Lower Body Strength-Training Versus Proprioceptive Exercises on Vertical Jump Capacity: A Feasibility Study

Charles Son, BS,[a] Adam Stewart, BS,[a] John Ward, DC, MA, MS,[b] and Kimary Farrar, DC[c]

Abstract

Objective: The purpose of this study was to test the feasibility of completing a study comparing the impact of lower body strength training to proprioceptive exercises on vertical jump capacity.
Methods: Thirty-nine college students (age 27.9 ± 6.4 y, height 1.69 ± 0.10 m, body mass 73.4 ± 15.9 kg: mean ± standard deviation) underwent baseline and post-testing of their vertical jump capacity using a Vertical Challenger and VICON motion analysis system. Participants were randomly assigned to 3 interventional groups between testing sessions: (1) lower body strength training, (2) lower body proprioceptive training, and (3) a no training control. Group 1 underwent supervised exercises 3 days a week at 2 sets of 12 repetitions of squats, seated knee extensions, standing knee flexions, and standing calf raises at approximately 25% of their body weight. Group 2 participants engaged in 4 supervised proprioceptive exercise stations 3 days a week involving BOSU ball stance, Rocker board, Bodyblade, and 1-legged stance exercises at 4 minutes per station. A between–within repeated-measures analysis of variance using between-participants factor "group" and within-participants factor "time" (baseline and post-test) was used to analyze data.
Results: Analysis of group × time indicated a small positive improvement in overall group performance for jump height at post-test, $F(2,36) = 5.527$, $P = .008$, $r = 0.36$. However, post hoc testing identified no statistically significant difference between groups for dependent variables.
Conclusions: This study determined that it was feasible to complete a study to compare 2 groups, but more than 1 week would be required to observe differences between lower body weight training and lower body proprioceptive training on vertical jump. (J Chiropr Med 2018;17:7-15)
Key Indexing Terms: *Exercise; Athletic Performance; Proprioception; Postural Balance*

Introduction

The ability to jump is critical to performance in many sports,[1] particularly basketball, football, and volleyball.[2] Jumping ability is often tested as an assessment of lower limb strength and power.[3] A common method of testing jumping ability is through the use of jump and reach tests, like vertical jump tests.[4] Maximal force,[5] the rate of force development,[5] and muscle stiffness[6] are all important factors in vertical jump performance.

Strength training is critical for many sports[7] and has been reported to improve vertical jump height.[8] This form of training involves lifting heavy weights while completing a small number of repetitions. One area that has not been adequately studied is how proprioceptive exercises affect vertical jump performance.

There is developing research that purports that proprioceptive training lowers athlete injury risk. One consequence of training and competing in athletics is the increased risk of injury.[9] This can have a negative consequence for the player, coach, and team overall.[10] Optimal training methods to improve performance while limiting injury risk as much as possible are critical.

Proprioceptive training represents activities that help individuals gain a better conscious awareness of their body and limbs in space.[11,12] It combines static and dynamic aspects[13,14] to include passive motion sense, active motion sense, limb position sense, and sense of heaviness, which provide feedback to the neuromuscular system. This feedback is performed by stimulating muscle spindles, Golgi tendon organs, and various joint afferents (Pacinian corpuscles, Ruffini endings, and free nerve endings).[15,16] Having injured and noninjured participants engage in proprioceptive training

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results in improved coordination for both groups.[17] Preliminary studies on adding proprioceptive exercises to training programs suggest they can reduce future injury risk by providing greater joint awareness.[18-21] The optimal way to engage in balance training to improve performance is not clear, but multiweek programs are most likely to result in improvements in function.[22] The effects of proprioceptive training on vertical jump ability have been minimally researched. This is concerning considering that in the 2014 review article by Aman et al[11] they described that "there is converging evidence that proprioceptive training can yield meaningful improvements in somatosensory and sensorimotor function."

The purpose of this study was to test the feasibility of completing a study comparing the impact of lower body strength training to proprioceptive exercises on vertical jump capacity. Feasibility of recruiting capabilities, data collection procedures, and observation of preliminary data trends were assessed.[23] The physiologic parameters measured were short-term differences in vertical jump capacity after 1 week of lower body strength training compared with 1 week of lower body proprioceptive exercises.

Methods

This study was reviewed and approved by the Texas Chiropractic College Institutional Review Board for human participants in accordance with the Declaration of Helsinki. This trial was registered with the University Hospital Medical Information Network Clinical Trials Registry (UMIN-CTR), trial number UMIN 000021192 (Reg# R00024438).

Study Design and Setting

The focus of this feasibility study was to compare the short-term impact of 1 week of lower body strength training to 1 week of lower body proprioceptive training on vertical jump capacity with the intent to engage in a longer multiweek study later (Figs 1 and 2). Participants engaged in baseline and post-testing of their vertical jump capacity using a Vertical Challenger (Tandem Sport, Louisville, Kentucky) combined with a VICON motion analysis system (VICON, Centennial, Colorado). During the study, participants were randomly assigned to the following groups: group 1 engaged in 1 week of lower body strength training, group 2 engaged in 1 week of lower body focused proprioceptive training, and group 3 was a no-training control that only engaged in pre- and post-testing.

Participant Recruitment and Preparation

Student volunteers were recruited via word of mouth from our college November 2015 through January 2016. Study applicants contacted the primary investigator for screening to determine if they met the inclusion and exclusion criteria. Inclusion criteria were college student 18 to 50 years of age, capable of bending knees and jumping, and fit enough to lift weights and engage in balance training. Exclusion criteria were muscle pathologic conditions (eg, myasthenia gravis, muscular dystrophy), balance-related pathologic conditions (eg, Meniere disease, orthostatic hypotension), joint-related pathologic conditions, using an assistive device (eg, cane, walker), limb surgeries, body mass index >30 kg/m^2, or pregnancy. They were notified in advance of the study inclusion and exclusion criteria and were provided with a copy of the informed consent.

Institutional Review Board–approved informed consent was provided and signed by all study applicants before participating in this study. Table 1 lists the attributes of the 3 study groups at baseline. This feasibility study used a convenience sample and did not follow an a priori power analysis. For data collection, men wore only black form-fitting shorts and black tennis shoes. Women wore black form-fitting shorts, a nonreflective sports bra, and black tennis shoes. Standardized attire was provided by the research laboratory and was used to reduce the likelihood of any reflective clothing interfering with the VICON camera recordings and to keep footwear standardized (eg, no sandals or minimalist shoes). Participants wore their own fitness attire for the week-long exercise sessions.

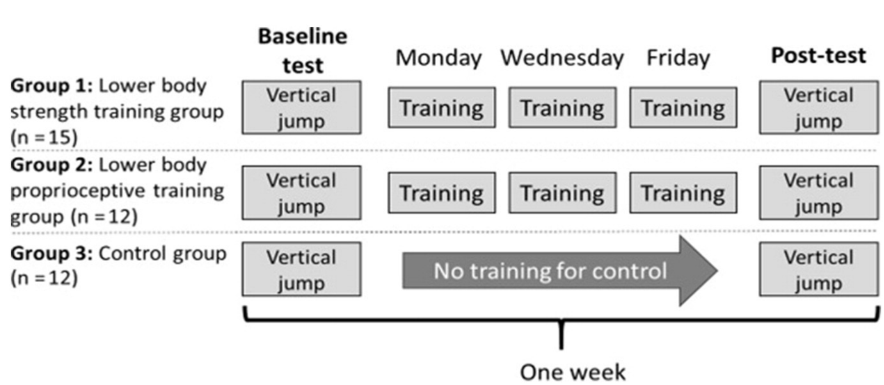

Fig 1. *Study design. The number of participants is marked in parentheses next to each group.*

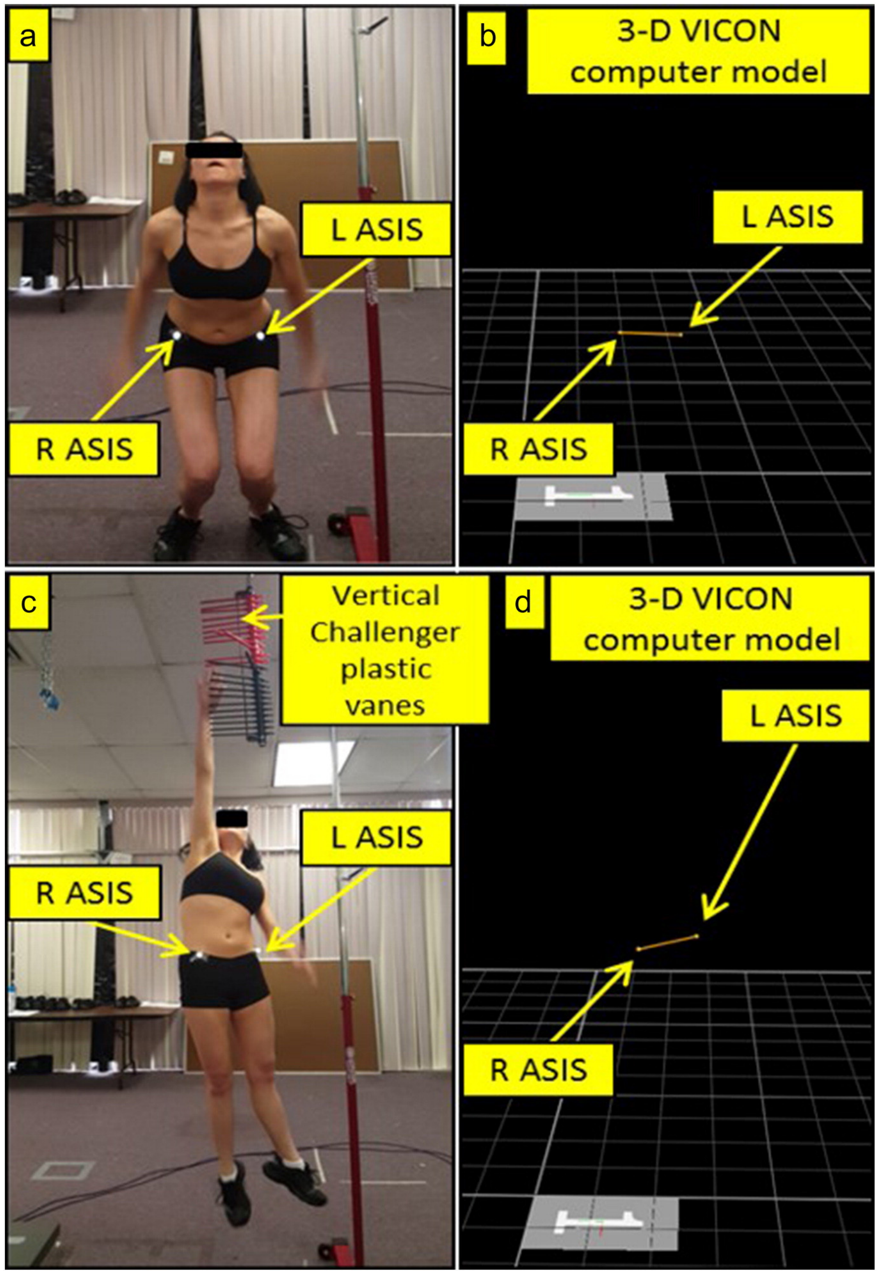

Fig 2. *Vertical jump test. Illustration of the start phase (A and B) and mid-point (C and D) of the vertical jump test used in this study. This was performed using a Vertical Challenger to measure jump height and VICON motion analysis system to measure hip vertical acceleration during the initial 0.3 second of upward motion. A camera flash was used in the photographs on the left to emphasize how the silver reflective markers glow to allow the VICON motion analysis cameras and software to render a 3-dimensional (3-D) image. The whole jumping task took approximately 2 minutes per participant.* LASIS, *left anterior superior iliac spine;* RASIS, *right anterior superior iliac spine.*

Vertical Jump Test

Researchers avoided playing music in the laboratory during vertical jump testing to avoid encouraging participants to try harder during 1 of the weeks as a result of hearing motivational music in some form and acting as a covariate.[24] Baseline testing and post-testing took place 7 to 8 AM because of research indicating a fluctuation in vertical jump performance throughout the day.[25,26] Participants did not stretch before engaging in the vertical jump test. Research has indicated that static stretching has a negative impact on vertical jump performance.[27] Participants stood next to the Vertical Challenger and extended their dominant arm upward

Table 1. *Baseline Participant Demographic and Anthropometric Attributes*

	Lower Body Strength Training Group	Lower Body Proprioceptive Training Group	No Training Control Group	*P*
Sex (M/F)	7/8	4/8	5/7	
Age (y)	28.5 ± 6.1	27.2 ± 6.9	27.7 ± 6.9	.863
Mass (kg)	74.8 ± 16.9	67.8 ± 12.3	77.5 ± 17.6	.317
Height (m)	1.70 ± 0.11	1.68 ± 0.11	1.68 ± 0.10	.837
Body mass index (kg/m^2)	25.8 ± 4.9	23.9 ± 3.7	27.6 ± 6.3	.229
Age range (y)	21-43	21-43	20-37	

Data presented as mean ± standard deviation unless otherwise specified.
F, female; *M,* male.

while a researcher recorded their starting vertical reach in relation to the bottom plastic vane. Researchers then placed 2 silver 19-mm MoCap (MoCap Solutions, Huntington Beach, California) reflective markers on each of the participants' anterior superior iliac spines with surgical tape. Next, participants assumed a squat jump (SJ) position.[28] An SJ was chosen, as opposed to a countermovement jump or drop jump, because it emphasized explosive power.[29] The SJ consisted of participants crouching down with their knees at approximately a 90° angle next to the Vertical Challenger as shown in Figure 2A.

For the vertical jump test, researchers began recording data with VICON as soon as the participant assumed the crouched position. They then instructed participants to jump as high as they could and push the plastic vanes anteriorly with their fingertips. The difference between the participant's standing vertical reach height and the maximum height he or she achieved, as a result of anterior vane displacement, was determined. The Vertical Challenger device was built with vanes separated in 1-inch increments. For standardization, all data in this manuscript are presented in international units (ie, centimeters instead of inches). Participants were not allowed any downward movements just before their vertical jump to take advantage of muscle elasticity properties. They were also not allowed to take initial steps or shuffle before their jump attempt.

Besides vertical jump height, researchers used VICON to measure initial velocity during the first 0.3 second of the research participant moving upward as determined by y-axis data from the centroid of the 2 anterior superior iliac spines points in relation to the start position of the squat jump.

Participants attempted to jump twice with a rest period of a few seconds in between attempts. Their greatest vertical jump height attempt was used for data analysis. The VICON MX camera motion analysis system used in this study consisted of 8 infrared Bonita 0.3-megapixel cameras (VICON, Centennial, Colorado) and was calibrated daily as suggested by the manufacturer. Kinematic data were recorded at 100 Hz using VICON software and processed with a Butterworth filter.

Exercise Intervention

As illustrated in Figure 3, participants in the lower body strength training group rotated through a series of 4 stations. They did this while being supervised by graduate assistants to ensure they used proper form and completed the correct number of repetitions. If participants were not capable of completing all the repetitions, they were asked to complete as many as they could. The supervision ratio was approximately 1:4 during the time-blocked training periods between research assistant to study participant. Research assistants calculated 25% of each study participant's individual weight and set resistance for each exercise at that amount. If the available weights were not exactly 25% of the participant's weight, the participant would use the next available higher weight. Weights in this study were available in 5-pound increasing increments. This 25% body weight restriction was dictated by our college's Institutional Review Board as a safety precaution for students who may not have been as physically active. Participants engaged in 2 sets of 12 repetitions of each of the 4 exercise stations. They were afforded 1 minute of rest between sets. The exercises consisted of squats, seated knee extensions, standing knee flexions, and standing calf raises. Squats were specifically chosen because of research indicating that they increase the strength of key muscles involved in vertical jump performance.[30]

As demonstrated in Figure 4, participants in the lower body proprioceptive training group likewise rotated through 4 exercise stations. Each station was 4 minutes long and participants engaged in the assigned exercise 30 seconds on and 30 seconds off for the entire 4 minutes. A similar time-blocked training schedule was used for participants in this group; however, the supervision ratio was 1:4. The activities consisted of BOSU ball (BOSU, Ashland, Ohio) stance, Rocker board (Sportsmith, Tulsa, Oklahoma), Bodyblade (Bodyblade, Playa del Rey, California), and 1-legged stance exercises. BOSU ball and Rocker board training were chosen because they create an unstable platform that can challenge proprioception[31] through low force production[32] but fatiguing actions.[33] The BOSU Balance Trainer was used to challenge balance and stabilization by having students perform the "centered position." The lower extremities were able to work individually with quick muscle reactions as opposed to the legs having to work together on the Rocker board. The Rocker board is a sensory-stimulating unstable surface designed to facilitate reactive postural control and train

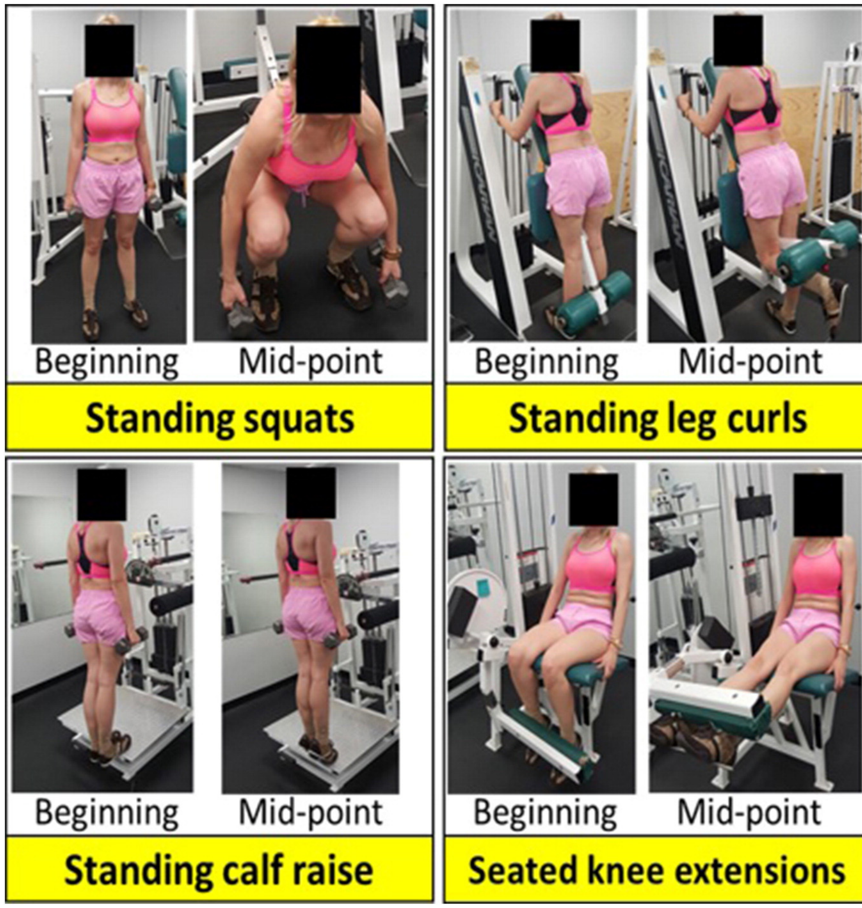

Fig 3. *Lower body strength training exercises. Participants engaged in 2 sets of 12 repetitions of each of the 4 exercises at approximately 25% of their body weight (or the next available heavier weight based on their individual body weight in 5-pound increments). If the participant was incapable of completing all of the repetitions, they were asked to complete as many as they could.*

proprioception. Bodyblade exercises were specifically chosen because perturbation has been reported to be valuable when engaging in proprioceptive lower limb training, and exercises using the Bodyblade create cyclical perturbations.[15] Perturbations destabilize the body, requiring reflexive neuromuscular responses to be made by large muscle groups, which positively affects proprioception over time.[34] The 2 Bodyblade exercises chosen targeted the core, gluteus medius, and gluteus maximus muscles of the lower body in addition to some upper body muscles. Having the participants stand on a compliant surface (foam pads) increased the proprioceptive challenge occurring by making their footing less stable during the exercise. The single leg stance is a common test used in evaluation of balance and sensory motor stimulation of the lower extremities. This test requires shifting of one's center of mass over 1 leg to reduce the base of support.

Statistical Analysis

The data were analyzed in SPSS Version 20.0 (IBM Corp., Armonk, New York). Results are reported as mean ± standard deviation (SD) unless otherwise specified. An analysis of variance (ANOVA) was used to compare between-group differences at baseline for demographic and anthropometric data. Levene test of homogeneity of variances was used. The α level of $P \le .05$ was considered statistically significant for between-group baseline data.

Kinematic data as .csv files were exported from VICON Nexus 1.7.1 software and entered into Excel (Microsoft Inc., Redmond, Washington). Initial 0.3-second vertical velocity was determined per participant per test iteration (before and after) and exported for further analysis in SPSS. The time window of 0.3 second was chosen because some participants were already on the down phase of their vertical jump by 0.5 seconds. A between-within repeated-measures ANOVA using between-participants factor "group" (lower body strength training, lower body focused proprioceptive training, or control) and within-participants factor "time" (baseline and post-test) was used to analyze study data. Mauchly test of sphericity was not observed as a result of having only 2 levels of the within-group repeated measure (before vs after).[35] Levene test of equality of error variances was used for study dependent variables. A Bonferroni post

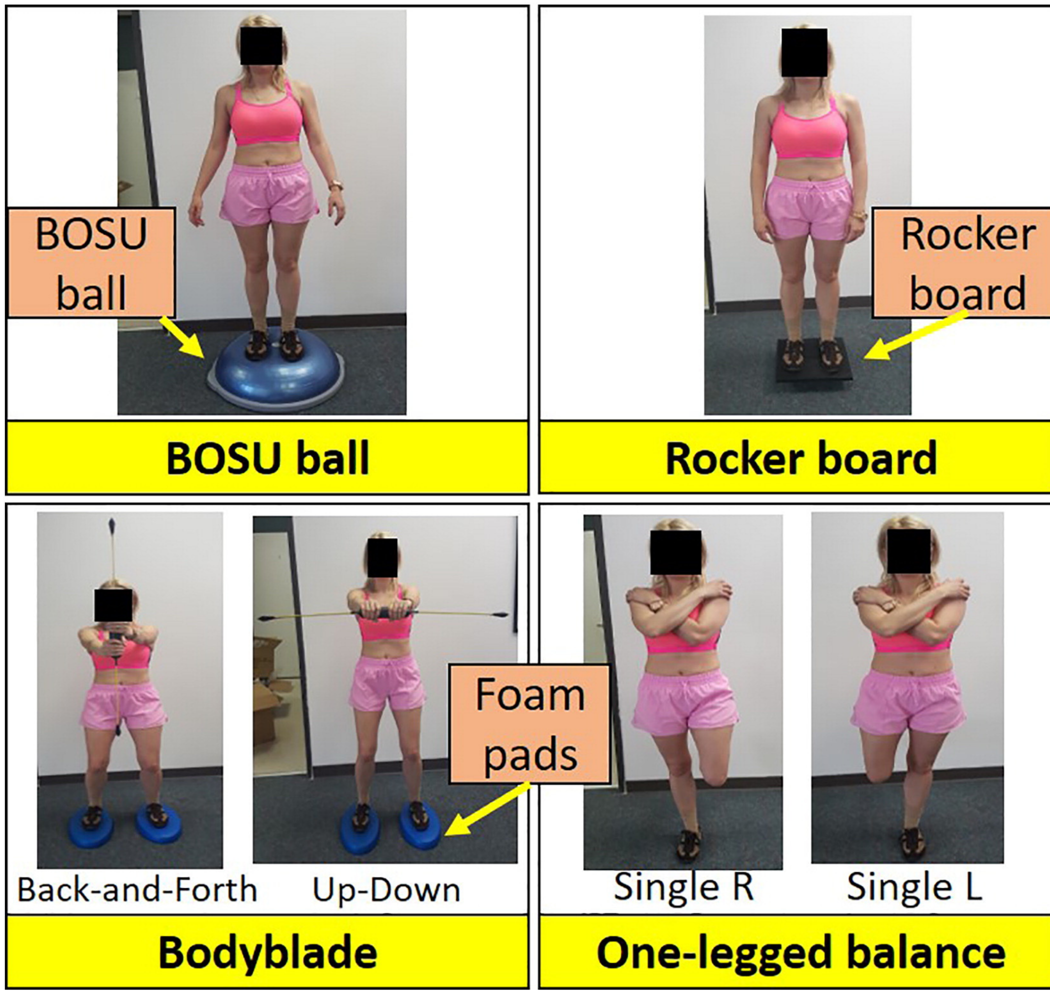

Fig 4. *Lower body focused proprioceptive training. Participants engaged in each of the 4 proprioceptive exercise stations for 4 minutes per station. With the Bodyblade exercises, participants stood on foam pads as they swung the blade side to side or up and down to increase difficulty.* L, *left;* R, *right.*

hoc test was conducted on statistically significant data among all ANOVAs to determine which condition was significant.[35] The α level of $P \le .05$ was considered statistically significant for all data analyses.

Results

This study design is feasible, and engaging in a longer duration study is possible with an appropriate incentive for research participants. The researchers were successful in recruiting for the short-term study. Two participants were excluded from participating in the study because they exceeded the BMI limitation. One participant was excluded from participating because of recent knee surgery. Three participants in the proprioceptive training group were dropped from the study; 1 failed to show up to the baseline test and the other 2 did not show up consistently to the 3 training sessions. As a result, only 12 participants completed all testing and training in group 2. Groups 1 and 3 did not have any participants drop out.

The data collection procedures were successful. Observation of preliminary data trends indicated small changes in study dependent variables. Analysis of group × time identified a small positive improvement in overall group performance for jump height at the post-test, $F(2,36) = 5.527$, $P = .008$, $r = 0.36$. However, post hoc testing identified no statistically significant difference between groups for study dependent variables. As shown in Figure 5A, participants in the strength training group marginally decreased their performance on the post-test (−1.5 ± 2.5 cm), whereas participants in the proprioceptive exercise group improved their performance (+1.8 ± 3.1 cm). The control group participants only slightly improved their performance on the post-test (+0.3 ± 2.4 cm). Analysis of group × time identified no significant change for initial 0.3 second of vertical velocity on the jump attempt (Fig 5B), $F(2, 36) = 0.205$, $P = .815$. There was no statistically significant difference between groups for initial velocity.

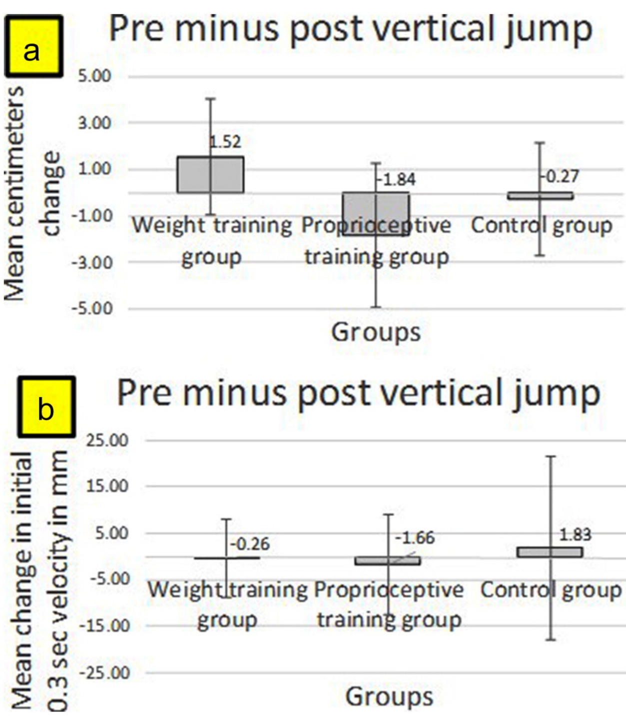

Fig 5. *Comparison of (A) squat jump height and (B) initial 0.3 second vertical velocity change between the 3 study groups. There were small changes in vertical jump height. Mean velocity was essentially the same before and after. Error bars represent standard deviation.*

Discussion

Training status (experienced vs novice),[28] training volume,[36] and learning effect[37] have all been reported to be critical to vertical jump performance. Most research literature supports combining weightlifting with plyometrics to maximize vertical jump performance.[30] The theory is that plyometric training helps store kinetic energy within the elastic components of lower limb muscles, which is more critical than strength training alone.[38]

This study attempted to analyze the feasibility of engaging in a larger, longer-duration future study to compare the short-term impact of strength training vs proprioceptive training on vertical jump performance. Recent research indicates that proprioceptive training may reduce injury risk, and studying proprioceptive training's relationship to vertical jump performance makes this study novel. The preliminary findings of this feasibility study were that 1 week of strength training or proprioceptive training had no statistically significant impact on vertical jump performance. However, it is interesting to note that performance on the vertical jump test started to improve for the proprioceptive training group after 1 week of training. A longer study of 4 weeks or more would be needed to effectively realize if greater improvements in athletic performance would occur. Existing literature indicates that during the first 5 weeks of exercise training most of the strength changes that occur are neurogenic in nature,[39] with participants becoming better able to control prime movers and suppress antagonists.[40] Similarly, Zech et al[22] reported in their balance training review article that multiple weeks of balance training are needed to develop appreciable gains in postural and neuromuscular control.

Research that can stem from this study include (1) engaging in a 4- to 6-week version of this study where strength training and proprioceptive training are compared, (2) comparing traditional plyometric jump training against a combination of plyometric and proprioceptive training on vertical jump performance, and (3) measuring the week-by-week change in vertical jump performance over several weeks with training to determine how vertical jump incrementally increases and where performance plateaus.

Limitations

One issue with this study is the limitation on external validity. The sample population was composed of random college students who were not necessarily athletes. Research indicates that well-trained athletes respond differently than the general population.[28] As a result, the findings of this study would apply more toward the general population than specifically athletes.

One week of exercise training was not long enough to gain appreciable changes in vertical jump capacity.[39] This feasibility study was intended to identify trends that might support longer training studies on vertical jump performance. Future studies will require greater research resources to incentivize participants for their time to attend multiple weeks of exercise training. The researchers' viewpoint was that students would be willing to participate in a study for 1 week, but they would not likely participate in a longer study without an appropriate incentive.

Another limitation is that this study did not follow a power analysis. After the study was completed, researchers performed a post hoc power analysis using G*Power Version 3.1.3 (Christian-Albrechts-Universität Kiel, Kiel, Germany)[41,42] with data from the lower body proprioceptive training group. In G*Power, assuming a post hoc t test for differences between 2 dependent means (matched pairs), 2 tails, effect size of 0.53 (as calculated from proprioceptive within-group r), α error probability of .05, and sample size of 12, the study power was 0.39. Despite this, it is normal in exercise science research to engage in underpowered studies using 10 to 20 participants per study group compared to observe data trends.[43,44]

Conclusion

This study design is feasible, and a longer study will provide clearer information on how proprioceptive exercises affect vertical jump performance compared with strength training. The short-term findings of this feasibility study were that 1 week of lower body weight training or lower body proprioceptive training was insufficient to induce a statistically significant improvement in vertical jump performance in relation to a control group. A longer training study would be needed to elucidate unique performance differences that may occur between strength training and proprioceptive training for vertical jump.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): C.S., A.S., J.W., K.F.
Design (planned the methods to generate the results): C.S., A.S., J.W., K.F.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): J.W., K.F.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): C.S., A.S., J.W.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): C.S., J.W., K.F.
Literature search (performed the literature search): C.S., A.S., K.W., K.F.
Writing (responsible for writing a substantive part of the manuscript): C.S., A.S., K.W., K.F.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): C.S., A.S., K.W., K.F.

Practical Applications

- Proprioceptive exercises have been reported to reduce the chance of injury in sports.
- The impact of proprioceptive training on vertical jump performance has rarely been studied.
- Proprioceptive training for 1 week was determined to cause marginal increases in vertical jump performance in relation to weight training.

References

1. Perez-Gomez J, Calbet J. Training methods to improve vertical jump performance. *J Sports Med Phys Fitness.* 2013;53(4):339-357.
2. Aragón-Vargas L, Gross M. Kinesiological factors in vertical jump performance: differences among individuals. *J Appl Biomech.* 1997;13:24-44.
3. Carlock J, Smith S, Hartman M, Morris R, Ciroslan D, Pierce K. Relationship between vertical jump power estimates and weightlifting ability: a field-test approach. *J Strength Cond Res.* 2004;18(3):534-539.
4. Leard J, Cirillo M, Katsnelson E, et al. Validity of two alternative systems for measuring vertical jump height. *J Strength Cond Res.* 2007;21(4):1296-1299.
5. Carvalho A, Mourão P, Abade E. Effects of strength training combined with specific plyometric exercises on body composition, vertical jump height and lower limb strength development in elite male handball players: a case study. *J Hum Kinet.* 2014;41:125-132.
6. Driss T, Lambertz D, Rouis M, Jaafar H, Vandewalle H. Musculotendinous stiffness of triceps surae, maximal rate of force production, and vertical jump performance. *Biomed Res Int.* 2015;2015:797256.
7. Baker D, Newton R. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J Strength Cond Res.* 2008;22(1):153-158.
8. Fry A, Kraemer W, Weseman C, et al. The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *J Strength Cond Res.* 1991;5(3):174-181.
9. Alhajaya M. Effects of proprioception training on knee joint position sense in male soccer athletes. *J Sociol Res.* 2015;6, https://doi.org/10.5296/jsr.v6i1.7544.
10. Hägglund M, Waldén M, Magnusson H, Kristenson K, Bengtsson H, Ekstrand J. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med.* 2013;47(12):738-742.
11. Aman J, Elangovan N, Yeh I, Konczak J. The effectiveness of proprioceptive training for improving motor function: a systematic review. *Front Hum Neurosci.* 2015;8:1075.
12. Goble D. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Phys Ther.* 2010;90(8):1176-1184.
13. Swanik C, Lephart S, Giannantonio F, Fu F. Reestablishing proprioception and neuromuscular control in the ACL-injured athlete. *J Sport Rehabil.* 1997;6(2):182-206.
14. Bruhn S, Gollhofer A, Gruber M. Proprioception training for prevention and rehabilitation of knee joint injuries. *Eur J Sports Traumatol Relat Res.* 2001;23(2):82-89.
15. Batson G. Update on proprioception: considerations for dance education. *J Dance Med Sci.* 2009;13(2):35-41.
16. Proske U, Gandevia S. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiol Rev.* 2012;92(4):1651-1697.
17. Myer G, Ford K, McLean S, Hewett T. The effects of plyometric vs dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med.* 2006;34(3):445-455.
18. Sadoghi P, von Keudell A, Vavken P. Effectiveness of anterior cruciate ligament injury prevention training programs. *J Bone Joint Surg Am.* 2012;94(9):769-776.
19. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective

controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc.* 1996;4(1):19-21.
20. Mandelbaum B, Silvers H, Watanabe D, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2 year follow-up. *Am J Sports Med.* 2005;33(7): 1003-1010.
21. Kean C, Behm D, Young W. Fixed foot balance training increases rectus femoris activation during landing and jump height in recreationally active women. *J Sports Sci Med.* 2006;5(1):138-148.
22. Zech A, Hubscher M, Vogt L, Banzer W, Hansel F, Pfeifer K. Balance training for neuromuscular control and performance enhancement: a systematic review. *J Athl Train.* 2010;45(4): 392-403.
23. Orsmond GI, Cohn ES. The distinctive features of a feasibility study: objectives and guiding questions. *OTJR.* 2015;35(3): 169-177.
24. van der Vlist B, Bartneck C, Mäueler S. moBeat: Using interactive music to guide and motivate users during aerobic exercising. *Appl Psychophysiol Biofeedback.* 2011;36(2):135-145.
25. Chtourou H, Souissi N. The effect of training at a specific time-of-day: a review. *J Strength Cond Res.* 2012;26(7):1984-2005.
26. Chtourou H, Aloui A, Hammouda O, Chaouachi A, Chamari K, Souissi N. Effect of static and dynamic stretching on the diurnal variations of jump performance in soccer players. *PLoS One.* 2013;8(8):e70534.
27. Cornwell A, Nelson A, Heise G, Sidaway B. Acute effects of passive muscle stretching on vertical jump performance. *J Hum Mov Stud.* 2001;40:307-324.
28. Cherif M, Said M, Chaatani S, Nejlaoui O, Gomri D, Abdallah A. The effect of a combined high-intensity plyometric and speed training program on the running and jumping ability of male handball players. *Asian J Sports Med.* 2012;3(1):21-28.
29. Martínez-López E, Benito-Martínez E, Hita-Contreras F, Lara-Sánchez A, Martínez-Amat A. Effects of electrostimulation and plyometric training program combination on jump height in teenage athletes. *J Sports Sci Med.* 2012;11(4): 727-735.
30. Adams K, O'Shea J, O'Shea K, Climstein M. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *J Appl Sport Sci Res.* 1992;6(1):36-41.
31. Sannicandro I, Cofano G, Rosa R, Piccinno A. Balance training exercises decrease lower-limb strength asymmetry in young tennis players. *J Sports Sci Med.* 2014;13(2):397-402.
32. Anderson K, Behm D. Maintenance of EMG activity and loss of force output with instability. *J Strength Cond Res.* 2004; 18(3):637-640.
33. Hoffman M, Sheldahl L, Buley K, Sandford P. Physiological comparison of walking among bilateral above-knee amputee and able-bodied participants, and a model to account for the differences in metabolic cost. *Arch Phys Med Rehabil.* 1997; 78(4):385-392.
34. Risberg M, Holm I, Myklebust G, Engebretsen L. Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: a randomized clinical trial. *Phys Ther.* 2007;87(6):737-750.
35. Field A. *Discovering Statistics Using SPSS IBM SPSS Statistics*. 4th ed. Thousand Oaks, CA: SAGE Publications; 2013.
36. Kubo K, Kanehisa H, Fukunaga T. Effects of resistance and stretching training program on the viscoelastic properties of human tendon structures in vivo. *J Physiol.* 2002;538(Pt 1): 219-226.
37. Hamada T, Sale D, MacDougall J, Tarnopolsky M. Post-activation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *J Appl Physiol.* 2000;88(6): 2131-2137.
38. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. *Br J Sports Med.* 2007; 41(6):349-355.
39. Moritani T, DeVries H. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med.* 1979;58(3):115-130.
40. Sale D. Neural adaptation to resistance training. *Med Sci Sports Exerc.* 1988;20(5 Suppl):S135-S145.
41. Faul F, Erdfelder E, Buchner A, Lang A. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods.* 2009;41(4): 1149-1160.
42. Erdfelder E, Faul F, Buchner A. GPOWER: A general power analysis program. *Behav Res Methods Instrum.* 1996;28(1): 1-11.
43. Crecelius A, Kirby B, Voyles W, Dinenno F. Augmented skeletal muscle hyperaemia during hypoxic exercise in humans is blunted by combined inhibition of nitric oxide and vasodilating prostaglandins. *J Physiol.* 2011;589(Pt 14):3671-3683.
44. Froyd C, Millet G, Noakes T. The development of peripheral fatigue and short-term recovery during self-paced high intensity exercise. *J Physiol.* 2013;591(5):1339-1346.